AD-A042 220   ARMY MISSILE RESEARCH AND DEVELOPMENT COMMAND REDSTO--ETC F/G 9/2

THE ANALYSIS OF COMPUTER AVAILABILITY.(U)

MAR 77 J ARSZMAN, J CAMPBELL

UNCLASSIFIED   DRDMI-TG-77-7   NL

| OF |

AD
A042220

END

DATE
FILMED
8-77

12

B.S.

TECHNICAL REPORT TG-77-7

THE ANALYSIS OF COMPUTER AVAILABILITY

Guidance and Control Directorate
Technology Laboratory

3 March 1977

Approved for public release; distribution unlimited.

U.S. ARMY
MISSILE
RESEARCH
AND
DEVELOPMENT
COMMAND

Redstone Arsenal, Alabama 35809

DMI FORM 1000, 1 APR 77

DISPOSITION INSTRUCTIONS

DESTROY THIS REPORT WHEN IT IS NO LONGER NEEDED. DO NOT RETURN IT TO THE ORIGINATOR.

DISCLAIMER

THE FINDINGS IN THIS REPORT ARE NOT TO BE CONSTRUED AS AN OFFICIAL DEPARTMENT OF THE ARMY POSITION UNLESS SO DESIGNATED BY OTHER AUTHORIZED DOCUMENTS.

TRADE NAMES

USE OF TRADE NAMES OR MANUFACTURERS IN THIS REPORT DOES NOT CONSTITUTE AN OFFICIAL INDORSEMENT OR APPROVAL OF THE USE OF SUCH COMMERCIAL HARDWARE OR SOFTWARE.

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: TG-77-7
2. GOVT ACCESSION NO.:
3. RECIPIENT'S CATALOG NUMBER:

4. TITLE (and Subtitle): (6) THE ANALYSIS OF COMPUTER AVAILABILITY.

5. TYPE OF REPORT & PERIOD COVERED: (9) Technical Rep[redacted].

6. ~~PERFORMING~~ ORG. REPORT NUMBER: (14) DRDMI - TG-77-7

7. AUTHOR(s): (10) Jerry Arszman [redacted] Jack Campbell

8. ~~CONTRACT~~ OR GRANT NUMBER(s):

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Commander
US Army Missile Research and Development Command
ATTN: DRDMI-TG
Redstone Arsenal, Alabama 35809

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
(16) ~~DA~~ 1X3643070212
AMCMS 634307.2120012

11. CONTROLLING OFFICE NAME AND ADDRESS
Command
US Army Missile Research and Development Command
ATTN: DRDMI-TI
Redstone Arsenal, Alabama 35809

12. REPORT DATE: (11) 3 Mar[redacted] [redacted]977

13. NUMBER OF PAGES: 43

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): (12) 42p.

15. SECURITY CLASS. (of this report): Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Computer down-time
Computer up-time
Stochastic processes

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Random computer failures were analyzed and modeled to provide the decision maker a quantitative measure of computer availability for scheduling purposes.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

410 138

1B

3 March 1977 TECHNICAL REPORT TG-77-7

THE ANALYSIS OF COMPUTER AVAILABILITY

Jerry Arszman and Jack Campbell

DA Project No. 1X364307D212
AMCMS Code No. 63407.2120012

Approved for public release; distribution unlimited.

Guidance and Control Directorate
Technology Laboratory
US Army Missile Research and Development Command
Redstone Arsenal, Alabama 35809

CONTENTS

I. INTRODUCTION

The random occurrence of computer down-time can cause delays in completing computer-dependent tasks if not accounted for in initial job duration estimates. But how can a phenomenon like computer failure be estimated when it evolves through time in a manner that is not completely predictable? The answer to this question has been obtained by applying random process modeling techniques to the study of a large scale scientific computer's* random down-times. The models developed in this study provide the decision maker a quantitative method of predicting computer availability for scheduling purposes. They can give answers in terms of probabilities to such questions as:

a) If the computer is down (up) now, what is the probability of it being up (down) after a specified amount of time has elasped?

b) What is the probability of experiencing N failures ($N = 0, 1, 2...$) within a specified time interval?

c) If the system has N failures today, what is the probability of having M failures tomorrow? ($M, N = 0, 1, 2, ...$).

The study was performed by deriving probability distributions from actual computer down-time data and then using expected values of these distributions as inputs to stochastic models of the computer's random up/down cycle. Two categories of stochastic processes were used:

a) Discrete time processes:

Discrete parameter Markov chain $\{X_n(t), t=0, 1, 2, ..., n=0, 1, 2, ...\}$.

b) Continuous time processes:

1) Poisson process $\{N(t), t \geq 0\}$.

2) Discrete parameter Markov process $\{X_n(t), t \geq 0, n = 0, 1, 2,...\}$.

These processes and their applications are discussed in Section III.

Six months of chronological data on computer down-time were obtained through the cooperation of the Directorate for Management Information Systems, US Army Missile Readiness Command and are included in Appendix A.

* Scientific Computer User's Guide, US Army Missile Command, October 1974.

II. DATA ANALYSIS

A. General Assumptions

For this study, the data obtained through the Directorate for Management Information Systems were not in the proper form for immediate incorporation into the stochastic models developed and applicable to the stated problem. The raw data, presented in Appendix A, had to be interpreted, modified, analyzed, and developed into usable data. In order to perform the required data transformation, it was necessary to make four major assumptions as follows:

a) The first assumption concerned the third shift operation of the computer. During the third shift, computer preventive maintenance and the lack of a sense of urgency in repairing computer failures result in interrupt and failure times which are not consistent with the first and second shift operations. Because of this situation, the data transformation was carried out using only the data from the first and second shift operation. These shifts covered the time from 7:45 a.m. to midnight.

b) The second assumption was the combining of related inputs into one failure. From past experience and from subsequent data analysis, multiple interrupts can actually be the manifestations of one basic problem or failure. Therefore, it interrupts occur within 2 hours of each other and have the same listed cause, these interrupts are combined into one unit which is called a failure.

c) Building on the definition of failure, the third assumption addresses a variable named operating time. The operating time will be defined as the failure interarrival time. This time will not include the time between interrupts which are assumed to be manifestations of one failure. This is also a reasonable assumption from the point of view of operating time being usable time. If the computer is up between interrupts but the time up is short, this time is essentially not usable unless a short job is processed and the system is entered soon after the machine comes up.

d) The fourth and final major assumption deals with the repair time. Following the same logic used in developing the failure and operating time assumptions, the repair time is assumed to include the total time necessary to correct a given failure. This repair time will include the down-time of related interrupts and the "unusable" up-time between related interrupts. The repair time will be the total elapsed time from first interrupt until the failure is repaired.

The following is a summary of the four major assumptions (definitions): Consider first and second shift operation only; failure is a

combination of related interrupts; operating time is the failure interarrival time; repair time is the total time to correct a failure.

B. Basic Data Transformation

Using the stated assumptions and a small programmable calculator, a basic data transformation was accomplished. Table 1 is an example of this data transformation. The raw data are in terms of interrupts: the time the interrupt started, the time the interrupt was corrected, the total time of the interrupt, and the cause of the interrupt. The transformed data are in terms useful for developing the necessary parameters and relationships to be used in modeling the computer availability as a stochastic process. The main points to be noted in Table 1 are the ramifications of combining related interrupts into failure phenomenon. In so doing, the up-time noted by the * is not used in determining computer operating time, but it is added to the down-time to get the total time for repair. Also, by combining two software interrupts, s, into one software failure, the number of interrupts on that particular day is one less than the actual number of interrupts. The transformed data are included in Appendix B. It is from these transformed data that the estimates of the distribution parameters were calculated.

C. Distribution of the Variables

Before the estimates of the distribution parameters could be used in the models, it was necessary to provide some assurances that the assumed distribution of the variables is justified. It is not possible to devise a statistical test to be certain of conformance to an assumed distribution; however, a chi-square goodness of fit test can be performed with the available data to test the null hypothesis that the data fit a particular distribution. As a refresher, Table 2 is an outline of the chi-square goodness of fit test. This test was used extensively in the data analysis not only to verify the use of a particular distribution, but also to support some of the major assumptions concerning failure, operating time, and repair time. This technique is used on most of the remaining data analyses covered in this section.

D. Chi-Square Test

Table 3 has several pieces of information. The chi-square test indicates the rejection of the hypothesis that the interrupts follow a Poisson distribution and the test indicates the failure to reject the hypothesis that the computer failures follow a Poisson distribution. The number of days on which observations were made and the average number of failures per day are also listed. Table 4 contains the same basic failure data but they are expressed in a different format. Table 4 shows the transition matrix for failures per day. Although 128 days of observation went into the development of this matrix, numerous zeros are in the lower right hand corner of the matrix.

TABLE 1. DATA TRANSFORMATION EXAMPLE

Day of Month	Time System Stopped	Time System Started	System Down (min)	Cause of Interrupt
1 Nov	11:57	12:06	9	H
1 Nov	12:35	12:50	15	O
1 Nov	13:40	13:50	10	S
1 Nov	14:04	14:12	8	S
1 Nov	15:05	15:38	33	H

Day of Month	Total Time Up	Total Time Down	Total Time Repair	Type of Failure	No. of Failures
1 Nov	27.70	0.15	0.15	H	
1 Nov	0.48	0.25	0.25	O	
1 Nov	0.83	0.17	0.53	S	4
1 Nov	0.23*	0.13			
1 Nov	0.88	0.55	0.55	H	

* The up-time is not used in determining computer operating time, but it is added to the down-time to get the total time for repairs.

TABLE 2. CHI-SQUARE "GOODNESS OF FIT" TEST

Test Statistic $\chi_o^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i}$

O_i = Observed frequency in i^{th} class

E_i = Expected frequency in i^{th} class according to hypothesized probability distribution

k = Number of class intervals

$\chi_0^2 \approx$ follows chi-square distribution with k-p-1 degrees of freedom

P = Number of parameters estimated by sample statistics

The hypothesis that the random variable conforms to the hypothesized distribution is rejected if

$$\chi_0^2 > \chi^2_{\alpha,\ k-p-1}$$

For tests in this project, $\alpha = 0.05$

Expected Frequency

Poisson

$$E_x = n\ p(x) = n \frac{e^{-\hat{\mu}} (\hat{\mu})^x}{x!}$$

Exponential

$$E_x = n\ p(x) = n\ F\ (x_2 - x_1)$$
$$= n\ [e^{-x_1\lambda} - e^{-x_2\lambda}]$$

TABLE 3. INTERRUPTS AND FAILURES

Interrupts				
	Class	O_i	E_i	
n = 128 days	0	60	44.2	H_o: Interrupts are Poisson
	1	36	47.0	
μ = 1.063 interrupts/ day	2	14	25.0	$\chi_o^2 = 16.3 > 5.99 = \chi^2_{0.05,2}$
	3	9	8.9	
	4	3 } 18	2.4 } 11.8	∴ Can Reject H_o
	5	5	0.5	
	8	1	0.0	

Failures				
	Class	O_i	E_i	
n = 128 days	0	60	56.4	H_o: Failures are Poisson
	1	42	46.2	
μ = 0.820 failures/ day	2	17	19.0	$\chi_0^2 = 1.88 \not> 5.99 = \chi^2_{0.05,2}$
	3	7 } 9	5.2 } 6.4	∴ Cannot reject hypothesis that failures are Poisson
	4	2	1.2	

TABLE 4. TRANSITION MATRIX

		0	1	2	3	4
	0	0.417	0.400	0.100	0.050	0.033
Failures	1	0.326	0.326	0.256	0.093	0
per	2	0.875	0.125	0	0	0
Day	3	0.667	0.333	0	0	0
	4	1.000	0	0	0	0

These zeros do not indicate an impossible solution; they indicate a situation which is not very likely to occur and needs more data points to define sufficiently.

E. Up-Time/Operating Time Analysis

Table 5 shows the up-time/operating time analysis. As in the interrupt/failure analysis, the basic assumptions are supported. The up-times do not conform to an exponential distribution; the operating times are exponentially distributed.

F. Down-Time/Repair Time Analysis

Proceeding to the down-time /repair time analysis, Table 6, the goodness of fit tests indicate that the assumed exponential character of these times can both be rejected. These results in themselves are almost catastrophic because application of the repair time data to the chosen random process model (paragraph III B) depends on an exponentially distributed repair time. Fortunately, a more thorough analysis of the data uncovers the bifurcated nature of the repair time distribution. The repair time can be divided into two distributions; the dividing point is 1 hour. Making this distinction there is a failure to reject the null hypotheses that the two distributions are exponential, Table 7. Apparently there are two distinct classes of failure. One class of failure is easily and quickly repaired; the other class requires either expert service or a basic machine restart time.

G. Data Analysis Summary

Table 8 is a data analysis summary. This summary contains the four major assumptions (definitions), the assumed distribution for the three variables (failures, operating time, repair time),

TABLE 5. UP-TIMES AND OPERATING TIMES

Goodness of Fit Tests				
Up-Times	Class	Observations	Expected	
$n = 134$	0-1	30	8.9	
$\mu = 14.58$	1-2	14	8.3	H_o: Up-times are exponential
	2-4	14	15.0	
$\lambda = 0.0686$	4-6	9	13.1	
	6-8	8	11.4	
	8-10	3	9.9	
	10-15	10	19.6	
	15-20	7	13.9	$\chi_0^2 > 50 > 15.51 = \chi^2_{0.05,8}$
	20-30	19	16.9	
	30-97	20	17.1	$\therefore$ Can reject H_o
Operating Times				
$n = 103$	0-2	13	10.4	H_0: Operating times are exponential
$\mu = 18.80$	2-4	14	9.3	
	4-6	9	8.4	
$\lambda = 0.0532$	6-8	8	7.6	
	8-10	10	14.1	
	15-20	7	10.8	
	20-30	19	15.0	$\chi_0^2 = 8.98 \not> 12.59 = \chi^2_{0.05.6}$
	30-97	20	20.0	$\therefore$ Cannot reject hypothesis Operating times are exponential

TABLE 6. DOWN-TIMES AND REPAIR TIMES

Down-Times	Class	O_i	E_i	
n = 136	0-0.2	47	25.1	H_0: Down-time is exponential
	0.2-0.3	26	10.7	
μ = 0.981	0.3-0.4	14	9.7	$\chi_0^2 > 45 > 31.43 = \chi^2_{0.05,20}$
	0.4-0.5	5	8.8	
λ = 1.019	⋮	⋮	⋮	$\therefore$ Can reject H_0
Maximum of 20 Classes				
Repair Times	Class	O_i	E_i	
n = 104	0.1-0.2	24	8.6	H_0: Repair time is exponential
	0.2-0.3	20	7.9	
μ = 1.255	0.3-0.4	11	7.3	$\chi_0^2 > 50 > 31.43 = \chi^2_{0.05,20}$
	0.4-0.5	7	6.7	
λ = 0.8658	⋮	⋮	⋮	$\therefore$ Can reject H_0

TABLE 7. REPAIR TIMES/TWO DISTRIBUTIONS

FIRST DISTRIBUTION < 1 HOUR				
	Class	Observations	Expected	
$n = 69$	0.1-0.2	24	27.9	H_0: Distribution is exponential
	0.2-0.3	19	16.6	
$\mu = 0.2934$	0.3-0.4	10	9.9	$\chi_0^2 = 5.2 \not> 7.81 = \chi^2_{0.05,3}$
	0.4-0.5	3	5.9	
$M_b = 0.1934$	0.5-1.0	13	8.1	$\therefore$ Cannot reject H_o
$\lambda = 5.171$				

SECOND DISTRIBUTION $\geq$ 1 HOUR				
	Class	Observations	Expected	
$n = 35$	1.0-1.5	7	7.3	H_0: Distribution is exponential
	1.5-2.0	6	5.8	
$\mu = 3.149$	2-3	8	8.2	$\chi_0^2 = 0.052 \not> 7.81 = \chi^2_{0.05,3}$
	3-4	5	5.1	
$M_b = 2.149$	4-13	9	8.5	
$\lambda = 0.465$				$\therefore$ Cannot reject H_0

and the estimates of the parameters of the assumed distributions. The data in Table 8 are the bases of the applications discussed in the next section.

III. RANDOM PROCESS MODELS AND THEIR APPLICATIONS

A. Discrete Time Processes

The computer is assumed to be observed at a discrete set of times. The successive observations are denoted by X_o, X_1, ..., X_n, ..., where the X_n are assumed to be random variables. The sequence $\{X_n\}$ is a Markov chain if each random variable X_n is discrete and

$$P\,[X_n = j_n \mid X_{n-1} = j_{n-1}, X_{n-2} = j_{n-2}, \ldots, X_o = j_o] =$$

$$P\,[X_n = j_n \mid X_{n-1} = j_{n-1}] \quad .$$

This is intuitively interpeted as: Given the "present" of the process, the "future" is independent of its "past." In addition, the process is assumed to be stationary and it is sufficient to specify the one-step transition probabilities:

$$P_{ij} = P\,[X_1 = j \mid X_o = i]$$

because the one-step transition probabilities at any step number are the same. The square matrix P whose elements are the P_{ij}'s is called the one-step transition matrix of a discrete parameter Markov chain. A five-state transition matrix was developed (Table 4) using the number of computer failures as states and a time interval of one day for a transition. The information contained in this transition matrix can be used to determine the probability of being in any state given a starting state after n days have elapsed. This can be done in two ways. One technique is to raise the matrix P to the n^{th} power. This operation would be necessary for every n days of interest. Another technique is the use of the Z transform to obtain a matrix whose elements are functions of n. This operation would result in fairly easily evaluated probabilities for any n, but the calculation of the Z transform solution involves evaluation of a 5 x 5 matrix.

Another approach to extracting information from this five-state transition matrix is to determine the steady-state or equilibrium probabilities. These steady-state probabilities are independent of the

initial state; therefore, the solution to the set of simultaneous equations will result in the steady-state probabilities. This set of equations is:

$$\Pi = \Pi P \qquad \Pi \text{ is a vector}$$

$$\sum_i \pi_i = 1 \qquad P \text{ is a transition matrix}, \quad \pi_i \text{ are components of } \Pi$$

Solving this set of equations by requiring $\sum \pi_i = 1$ to be used in the solution results in the steady-state probabilities,

$$\Pi = (0.469 \quad 0.329 \quad 0.131 \quad 0.54 \quad 0.013)$$

To give some physical interpretation to these probabilities: if the computer operation was observed for 100 days, then the following situation is predicted:

No. of days with no failures:	47
No. of days with one failure:	33
No. of days with two failures:	13
No. of days with three failures:	5
No. of days with four failures:	1

B. Continuous Time Processes

Phillips* describes continuous time stochastic processes as being similar in most respects to discrete time stochastic processes. He cautions that additional complexities can occur due to each infinitesimal instant being available for a possible transition.

1. The Poisson Process

The occurrence of computer breakdowns can be described by a counting function $\{N(t), t \geq 0\}$ which represents the number of breakdowns that have occurred during the time period from 0 to t. According to Parzen,** this counting process is said to be a Poisson process with mean rate λ, if the following assumptions are fulfilled:

(i) $\{N(t), t \geq 0\}$ has stationary independent increments.

(ii) The number of counts in a specified interval, say t-s, $(0 < s < t)$, is Poisson distributed such that

---

* Phillips, D. Ravindran, A., and Solberg, J., Operations Research: Principles and Practice, New York: John Wiley and Sons, Inc., 1976.

** Parzen, E., Stochastic Processes, New York: Holden-Day, Inc., 1962.

$$P[N(t)-N(s) = k] = \begin{cases} \dfrac{e^{-\lambda(t-s)}\{\lambda(t-s)\}^k}{k!}, & 0 < s < t \\ & K = 0, 1, 2, \ldots \\ 0, \text{ otherwise} & \end{cases}$$

The mean rate λ is interpreted to be the rate of arrival breakdowns. The parameter for this process, $\lambda(t-s)$, is a function of time and increases linearly with the time interval. An example of the Poisson model to predict computer failures for a specified time interval is provided in Figure 1. Poisson distribution graphs for two time intervals are illustrated. The probability of the occurrence of zero failures decreases as the time interval increases.

TABLE 8. DATA ANALYSIS SUMMARY

(First and Second Shift Operation)

Failures

Combination of related interrupts
(Same cause within two hours)

Poisson distribution, μ = 0.820 failures/day

Operating Time

Failure interarrival time

Exponential distribution, λ = 0.0532 failures/hour

Repair Time

Total time to correct one failure
(include nonusable up-time)

Bifurcated Distribution

Time < 1 hour - Exponential, λ = 5.171 repairs/hour

Time $\leq$ 1 hour - Exponential, λ = 0.465 repairs/hour

2. The Discrete Parameter Markov Process

The computer's random up-time/down-time events occur as illustrated in Figure 2. The system can be in one of two states, "on" or "off." If it is "on," it operates for a random time before breakdown. If it is "off," it is off for a random time before being repaired. This phenomenon can be modeled as a two-valued stochastic process termed a discrete parameter Markov process. It has discrete parameters but a continuous state space (time). The assumptions for the continuous time Markov are:

(i) The process satisfies the Markov property.

(ii) The process is stationary.

(iii) The probability of transition from one state to another in a short time interval Δt is proportional to Δt.

(iv) The probability of two or more changes of state in a short interval Δt is zero.

The transition probabilities $p_{ij}(t)$ can be derived based on these assumptions. The subscripts $_1$ and o denote "up" and "down" respectively. Then, from assumption (iii),

$$P\text{ [repair transition in } \Delta t] = P_{01}(\Delta t) = \nu\Delta t \tag{1}$$

$$P\text{ [breakdown transition in } \Delta t] = P_{1_0}(\Delta t) = \lambda\Delta t \tag{2}$$

The function $p_{01}(t + \Delta t)$ or the probability that the computer is in State 1 (up) at time $t + \Delta t$ is now considered, given that it was in State 0 (being repaired) at time zero. Either the computer was being repaired at time t and was put into operation during the interval Δt, or it was operating at time t and continued to operate for the short interval Δt. In equation form,

$$P_{01}(t + \Delta t) = P_{00}(t)\, P_{01}(\Delta t) + P_{01}(t)\, P_{11}(\Delta t) \quad . \tag{3}$$

$\{N(t), t \geq 0\}$ = NUMBER OF FAILURES K OCCURRING IN TIME INTERVAL t

$$P[N(t) = K] = \frac{e^{-\lambda t}(\lambda t)^k}{K!}, \text{ WHERE } \lambda = 0.0532 \text{ FAILURES/HOUR}$$

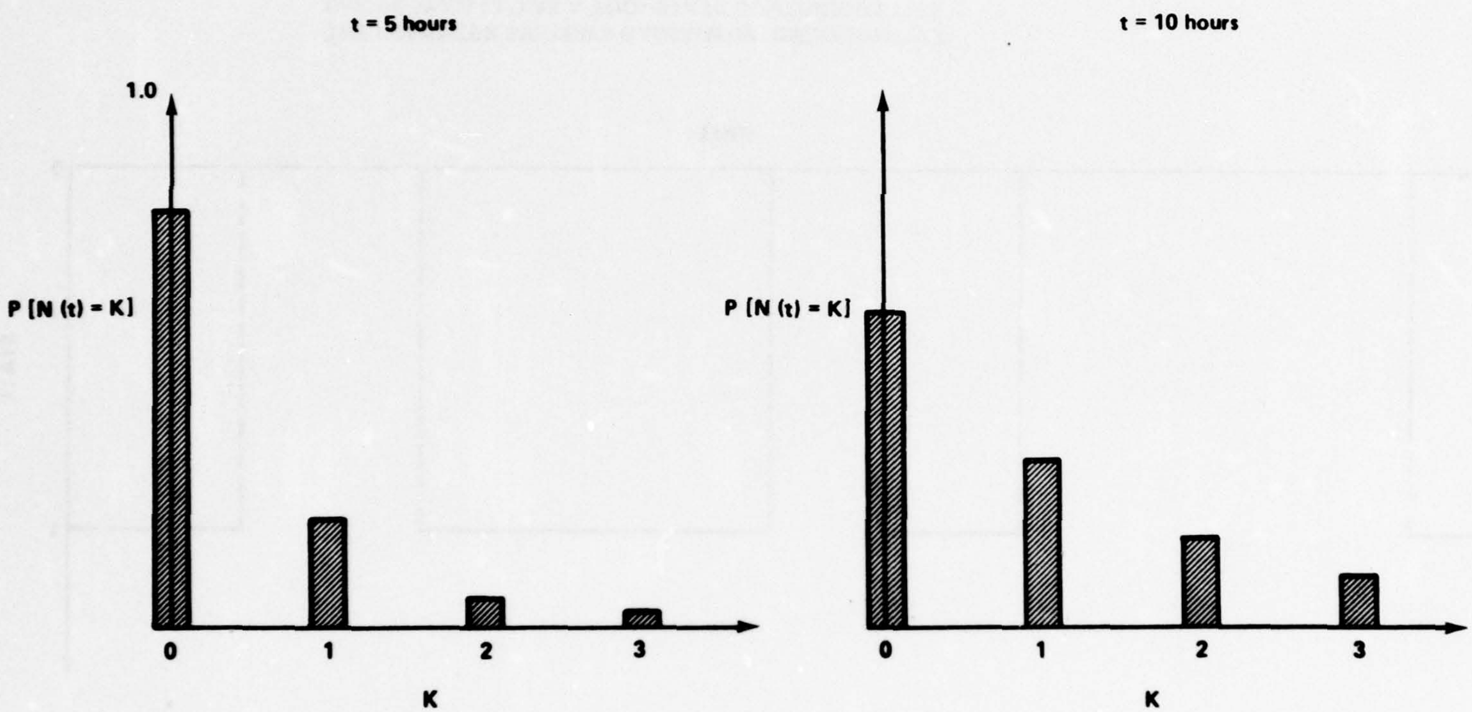
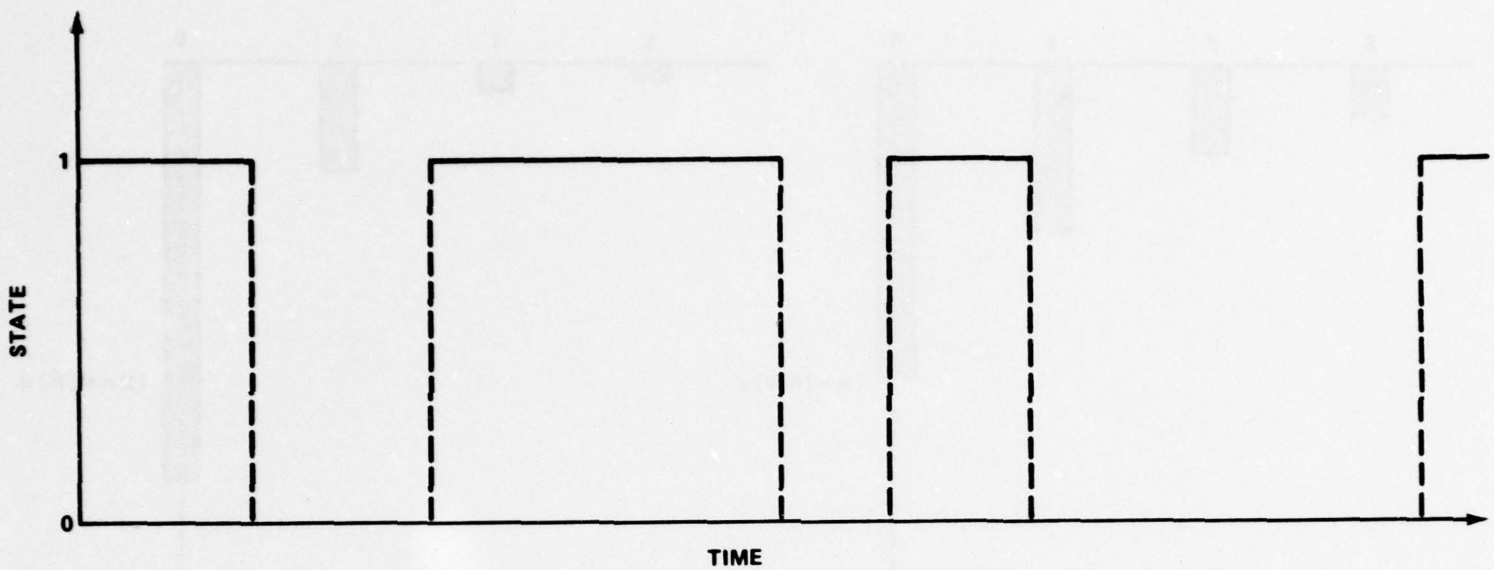


Figure 1. A stochastic Poisson process.



THE COMPUTER SYSTEM'S RANDOM UPTIME/DOWNTIME CAN BE MODELED AS A TWO-STATE CONTINUOUS TIME STOCHASTIC PROCESS.

Figure 2. Computer's random on/off cycle.

This is a special case of the Chapman-Kolmogorov equations for the continous time case. Assumption (i) is required to permit multiplication of the probabilities referring to events during t and to events during Δt. Assumption (ii) is required to permit use of the same probability functions for the interval t and for the later interval Δt. Equations (1) and (2) are substituted into Equation (3) and manipulated to obtain the difference equation

$$\frac{P_{01}(t + \Delta t) - P_{01}(t)}{\Delta t} = \lambda P_{00}(t) - \nu P_{01}(t) \ . \tag{4}$$

Taking the limit of both sides of Equation (4) as Δt approaches zero results in the differential equation

$$\frac{dp_{01}(t)}{dt} = \lambda p_{00}(t) - \nu p_{01}(t) \ . \tag{5}$$

The other three transition functions can be derived similarly:

$$\frac{dp_{00}(t)}{dt} = -\lambda p_{00}(t) + \nu p_{01}(t) \tag{6}$$

$$\frac{dp_{10}(t)}{dt} = -\lambda p_{10}(t) + \nu p_{11}(t) \tag{7}$$

$$\frac{dp_{11}(t)}{dt} = \lambda p_{10}(t) - \nu p_{11}(t) \ . \tag{8}$$

Equations (5) through (8) are a system of linear first-order differential equations with constant coefficients. They can be solved directly using Laplace transforms and the initial conditions

$$P_{ij}(0) = \begin{cases} 1, & i = j \\ 0, & \text{otherwise} \end{cases} \ .$$

The solutions are

$$P_{00}(t) = \frac{1}{(\lambda + \nu)} (\lambda + \nu e^{-(\lambda+\nu)t})$$

$$P_{01}(t) = \frac{1}{(\lambda + \nu)} (1 - e^{-(\lambda+\nu)})$$

$$P_{10}(t) = \frac{1}{(\lambda + \nu)} (1 - e^{-(\lambda+\nu)t})$$

$$P_{11}(t) = \frac{1}{(\lambda + \nu)} (\nu + \lambda e^{-(\lambda+\nu)t})$$

In matrix form:

$$\overline{P}(t) = \begin{bmatrix} P_{00}(t) & P_{01}(t) \\ P_{10}(t) & P_{11}(t) \end{bmatrix} = \frac{1}{\lambda + \nu} \begin{bmatrix} \lambda + \nu e^{-(\lambda+\nu)t} & \nu - \nu e^{-(\lambda+\nu)t} \\ \lambda - \lambda e^{-(\lambda+\nu)t} & \nu + \lambda e^{-(\lambda+\nu)t} \end{bmatrix} .$$

The sum of the terms in each row is 1 as they should be in order to represent Markov probabilities. Taking the limit of $\overline{P(t)}$ as t approaches infinity,

$$\overline{P} = \begin{bmatrix} \frac{\lambda}{\lambda + \nu} & \frac{\nu}{\lambda + \nu} \\ \frac{\lambda}{\lambda + \nu} & \frac{\nu}{\lambda + \nu} \end{bmatrix}$$

the steady-state probabilities are obtained.

This model is now ready to be exercised using the expected values for operating times and repair times obtained in Paragraph 2. The value for λ is 1/18.8 hours but two values for ν must be considered due to the bifurcated repair time distribution.

CASE I: Computer Repair Time $\leq$ 1 hour

$$p\ [\text{CASE I}] = \frac{\text{Number of Failures} \leq 1 \text{ Hour}}{\text{Total Number of Failures}} = 2/3$$

mean repair time for Case I = 0.1934 hour

$\nu_1 = 1/0.1934 = 5.17/\text{hour}$

$\lambda = 1/18.8 = 0.0532/\text{hour}$

$$\overline{P}_I(t) = \frac{1}{5.22}\begin{bmatrix}(0.0532 + 5.17e^{-5.22t}) & 5.17\ (-e^{-5.22t}) \\ 0.0532\ (1 - e^{-5.22t}) & (5.17 + 0.0532e^{-5.22t})\end{bmatrix}$$

CASE II: Computer Repair Time > 1 hour

p[CASE II] = 1 - p [CASE I] = 1/3

mean repair time for CASE II = 2.149 hours

$\nu_2 = 1/2.149 = 0.4653/\text{hour}$

$\lambda = 0.0532/\text{hour}$

$$\overline{P}_{II}(t) = \frac{1}{0.5185}\begin{bmatrix}(0.0532 + 0.4653e^{-0.5185t}) & 0.4653\ (1 - e^{-0.5185t}) \\ 0.0532\ (1 - e^{-0.5185t}) & (0.4653 + 0.532e^{-0.5185t})\end{bmatrix}$$

Plots of the four transition probabilities as a function of time for Cases I and II are provided in Figures 3 through 6. The combined Case I and II probabilities are also shown for each transition state. The combined functions were obtained by using the following equation:

$$\overline{P}_{I+II}(t) = \frac{2}{3}\,\overline{P}_I(t) + \frac{1}{3}\,\overline{P}_{II}(t) \quad .$$

The combined transition matrix would be used unless a conditional probability situation occurs. For example, if the computer is down now and has been down continuously for over 1 hour, the Case II transition curves could be used directly to determine state probabilities $p_{00}(t)$ and and $p_{01}(t)$. However, if the system is up now and the probability of it staying up for a specified time interval is wanted, the combined probability curve in Figure 6 should be used because conditional probability information is not available.

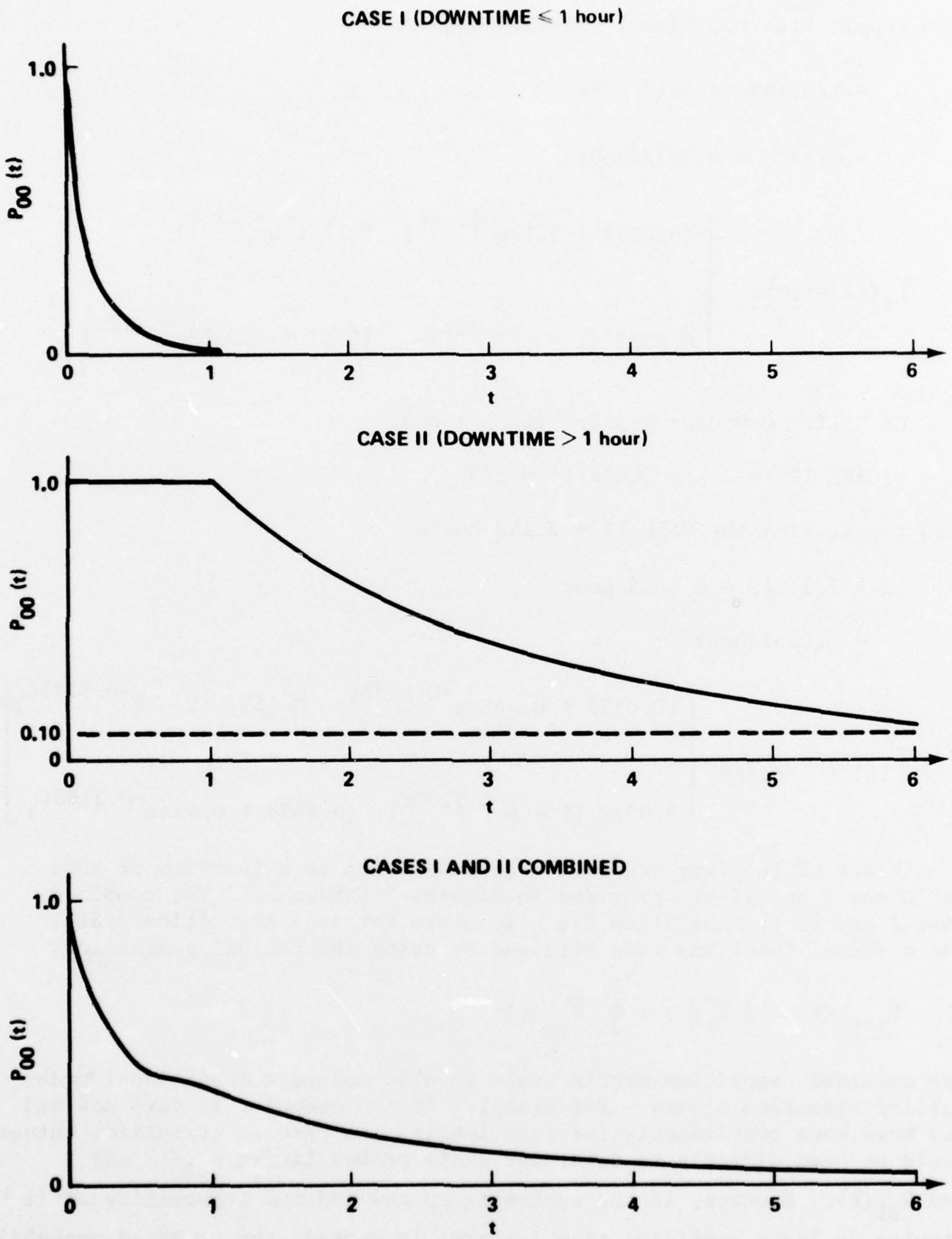


Figure 3. Probability of remaining "down."

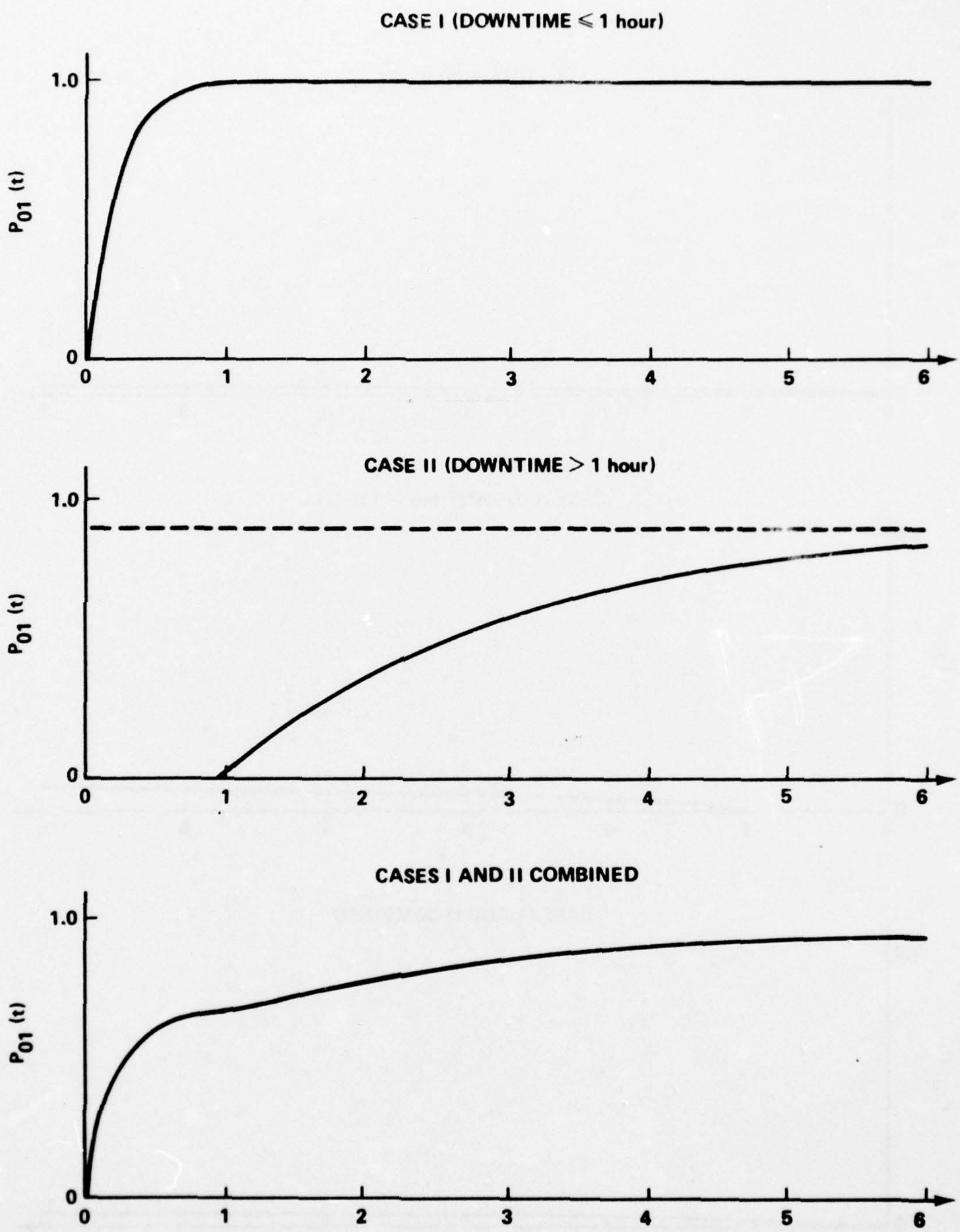


Figure 4. Probability of coming "up."

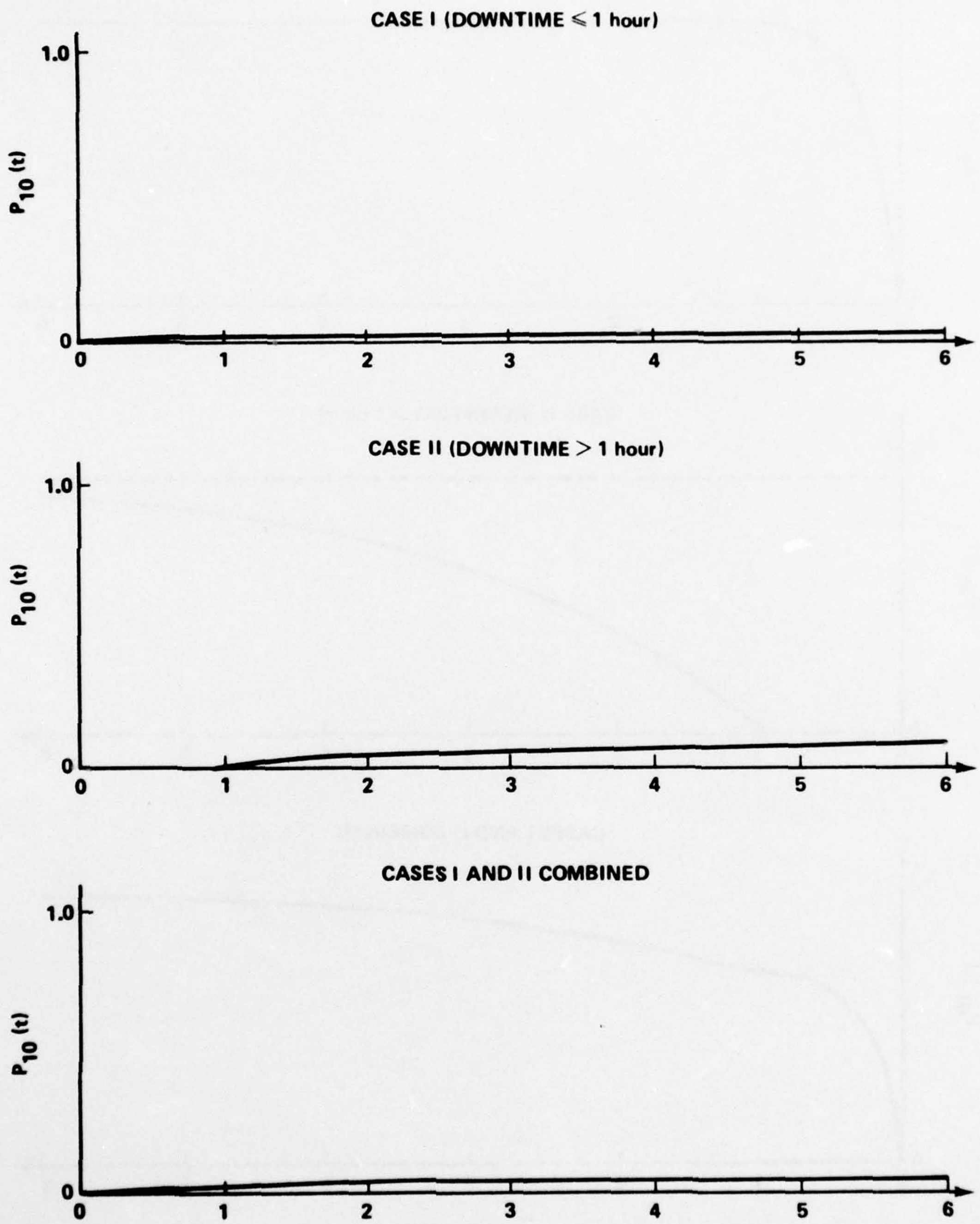


Figure 5. Probability of going "down."

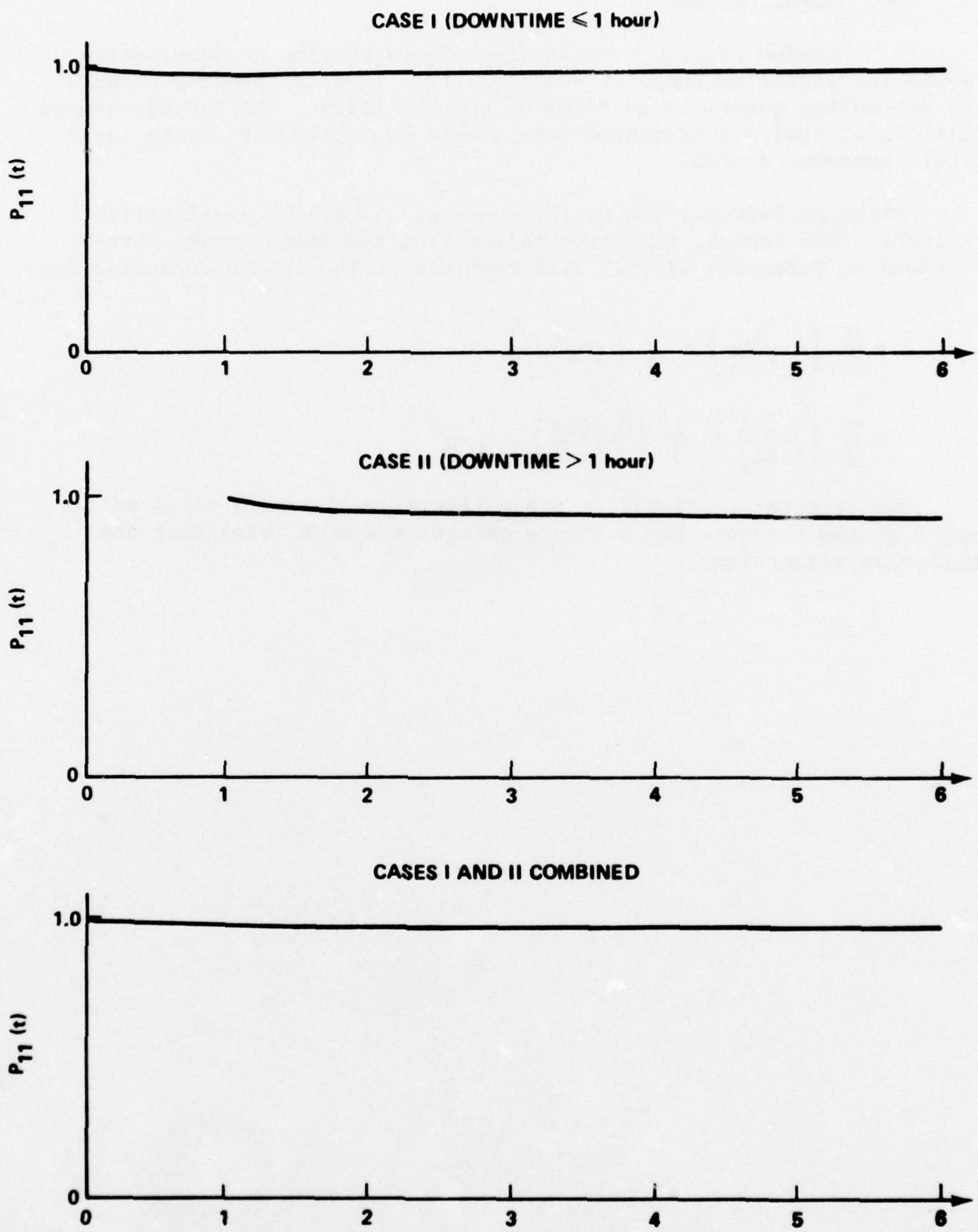


Figure 6. Probability of remaining "up."

IV. CONCLUSIONS

Random process modeling techniques provide a quantitative means for assessing computer availability. They can provide answers to scheduling questions in terms of probabilities. The techniques and methods of analysis presented here should be applicable to any large scale computer system.

Although failures occur, the computer has a high availability factor. This factor, rho, is obtained from the steady state matrix derived in Paragraph III B. With combined probabilities accounted for:

$$\rho = \frac{2}{3}\left(\frac{\nu_1}{\lambda + \nu_1}\right) + \frac{1}{3}\left(\frac{\nu_2}{\lambda + \nu_2}\right)$$

$$= \frac{2}{3}\left(\frac{5.17}{5.22}\right) + \frac{1}{3}\left(\frac{0.4653}{0.5185}\right) = 0.96 \quad .$$

The computer availability probabilities will remain valid unless major system hardware and software changes are made (violating the Markovian assumptions).

Appendix A. CHRONOLOGICAL DATA ON COMPUTER DOWN-TIME

CDC-6600 DOWN TIME CHRONOLOGY FOR 26 MAY - 25 JUNE 1976

DAY OF MONTH	TIME SYSTEM STOPPED		TIME SYSTEM UP	MINUTES SYSTEM DOWN	CAUSE OF INTERRUPTION
26		-		0	----------------
27	15:30	-	15:35	5	SOFTWARE
27	18:09	-	18:15	15	SOFTWARE
28	13:54	-	15:15	81	OTHER
1	11:33	-	12:11	38	SOFTWARE
1	15:11	-	19:30	257	OTHER
2	13:08	-	13:17	9	SOFTWARE
3		-		0	----------------
4	04:35	-	04:57	22	OTHER
7		-		0	----------------
8	13:08	-	13:18	10	OTHER
9	19:53	-	20:03	10	HARDWARE
10	16:35	-	21:53	318	OTHER
11	07:45	-	14:28	403	OTHER
11	15:09	-	15:15	6	OTHER
14	19:20	-	19:30	10	HARDWARE
15	07:45	-	08:02	17	OTHER
15	16:40	-	16:51	11	OTHER
16		-		0	----------------
17	14:14	-	14:22	8	SOFTWARE
17	15:40	-	16:02	22	HARDWARE
17	16:02	-	16:10	8	OTHER
18		-		0	----------------
21		-		0	----------------
22		-		0	----------------
23	10:15	-	10:46	31	HARDWARE
24		-		0	----------------
25	16:00	-	16:12	12	SOFTWARE

TOTAL HARDWARE DOWN TIME = 73 TOTAL SOFTWARE DOWN TIME = 87 TOTAL OTHER DOWN TIME = 1133

TOTAL HARDWARE INTERRUPTIONS = 4 TOTAL SOFTWARE INTERRUPTIONS = 6 TOTAL OTHER INTERRUPTIONS = 10

CDC-6600 DOWN TIME CHRONOLOGY FOR 26 JUNE - JULY 1976

DAY OF MONTH	TIME SYSTEM STOPPED		TIME SYSTEM UP	MINUTES SYSTEM DOWN	CAUSE OF INTERRUPTION
28	14:47	-	15:10	23	OTHER
29	07:56	-	08:06	10	HARDWARE
29	10:38	-	10:59	21	OTHER
30		-		0	---------------
1	01:16	-	01:26	10	HARDWARE
1	05:06	-	05:07	1	HARDWARE
1	05:07	-	05:21	14	HARDWARE
1	07:45	-	08:25	40	HARDWARE
2	10:25	-	10:50	25	HARDWARE
2	00:50	-	01:00	10	HARDWARE
2	06:50	-	07:00	10	OTHER
6		-		0	---------------
7	04:15	-	04:25	10	HARDWARE
7	04:47	-	05:02	15	OTHER
7	14:22	-	14:33	17	HARDWARE
7	14:55	-	14:58	3	HARDWARE
7	16:01	-	16:12	11	HARDWARE
8	10:00	-	11:17	77	OTHER
6	17:20	-	17:30	10	SOFTWARE
8	21:45	-	22:07	22	HARDWARE
9		-		0	---------------
12	07:58	-	08:41	43	HARDWARE
12	12:45	-	12:53	8	HARDWARE
12	13:10	-	14:12	62	HARDWARE
13		-		0	---------------
14	08:19	-	08:43	24	HARDWARE
15	10:25	-	10:35	10	HARDWARE
15	12:43	-	12:50	7	HARDWARE
15	13:25	-	14:02	37	HARDWARE
16		-		0	---------------
19		-		0	---------------
20		-		0	---------------
21	16:15	-	17:30	75	HARDWARE
22	17:[illegible]	-	17:05	6	OTHER
23		-		0	---------------

TOTAL HARDWARE DOWN TIME = 439 TOTAL SOFTWARE DOWN TIME = 10 TOTAL OTHER DOWN TIME = 152

TOTAL HARDWARE INTERRUPTIONS = 20 TOTAL SOFTWARE INTERRRUPTIONS = 1 TOTAL OTHER INTERRUPTIONS = 6

CDC-6600 DOWN TIME CHRONOLOGY FOR 26 JULY - AUGUST 1976

DAY OF MONTH	TIME SYSTEM STOPPED		TIME SYSTEM UP	MINUTES SYSTEM DOWN	CAUSE OF INTERRUPTION
26	14:50	-	15:02	12	OTHER
27		-		0	---------------
28		-		0	---------------
29		-		0	---------------
30	15:15	-	15:25	10	OTHER
2	11:26	-	13:06	160	HARDWARE
2	16:44	-	16:51	7	HARDWARE
3	00:10	-	00:20	10	SOFTWARE
4	09:40	-	10:09	29	HARDWARE
4	11:23	-	12:43	80	HARDWARE
4	14:36	-	14:52	16	SOFTWARE
5		-		0	-----------------
6	17:45	-	18:00	15	HARDWARE
9	08:15	-	08:24	9	HARDWARE
9	16:19	-	16:41	22	OTHER
10		-		0	---------------
11		-		0	---------------
12		-		0	---------------
13		-		0	---------------
16	21:00	-	09:35	741	HARDWARE
17	11:32	-	11:48	16	SOFTWARE
18	15:45	-	16:02	17	OTHER
19	07:45	-	09:26	101	HARDWARE
19	15:02	-	15:12	10	OTHER
19	16:15	-	19:50	215	HARDWARE
20		-		0	----------------
23	09:16	-	09:35	19	OTHER
24	16:05	-	20:32	287	OTHER
25	10:12	-	10:30	18	OTHER
25	13:38	-	14:20	42	HARDWARE

TOTAL HARDWARE DOWN TIME = 1399 TOTAL SOFTWARE DOWN TIME = 42 TOTAL OTHER DOWN TIME = 375

TOTAL HARDWARE INTERRRUPTIONS = 10 TOTAL SOFTWARE INTERRUPTIONS = 3 TOTAL OTHER INTERRUPTIONS = 8

CDC-6600 DOWN TIME CHRONOLOGY FOR 26 AUGUST - 25 SEPT 1976

DAY OF MONTH	TIME SYSTEM STOPPED		TIME SYSTEM UP	MINUTES SYSTEM DOWN	CAUSE OF INTERRUPTION
26		-		0	---------------
27		-		0	---------------
30		-		0	---------------
31	08:43	-	08:50	7	OTHER
31	09:10	-	09:29	19	HARDWARE
31	09:40	-	10:40	60	OTHER
31	11:18	-	13:07	109	HARDWARE
1		-		0	---------------
2	14:00	-	14:08	8	OTHER
3		-		0	---------------
7	07:45	-	20:10	745	OTHER
8	10:13	-	10:30	17	OTHER
8	16:42	-	17:07	25	SOFTWARE
9		-		0	---------------
10		-		0	---------------
13		-		0	---------------
14	09:06	-	09:28	22	HARDWARE
15		-		0	---------------
16	10:05	-	10:20	15	HARDWARE
16	16:37	-	16:47	10	SOFTWARE
16	17:50	-	18:70	40	OTHER
17	18:30	-	18:47	17	OTHER
17	20:10	-	21:19	60	OTHER
20	07:45	-	08:30	45	HARDWARE
20	09:09	-	09:12	3	OTHER
20	09:55	-	10:12	17	OTHER
20	10:25	-	10:58	33	OTHER
21		-		0	---------------
22		-		0	---------------
23		-		0	---------------
24		-		0	---------------

TOTAL HARDWARE DOWN TIME = 210   TOTAL SOFTWARE DOWN TIME = 35   TOTAL OTHER DOWN TIME = 1007

TOTAL HARDWARE INTERRUPTIONS = 5   TOTAL SOFTWARE INTERRUPTIONS = 2   TOTAL OTHER INTERRUPTIONS = 11

CDC-6600 DOWN TIME CHRONOLOGY FOR 26 SEPT - 25 OCT 1976

DAY OF MONTH	TIME SYSTEM STOPPED		TIME SYSTEM UP	MINUTES SYSTEM DOWN	CAUSE OF INTERRUPTION
27	08:30	-	09:20	50	HARDWARE
27	10:10	-	10:36	26	HARDWARE
28	15:20	-	15:34	14	OTHER
29		-		0	----------------
30	06:00	-	10:33	273	OTHER
1		-		0	----------------
4		-		0	----------------
5		-		0	----------------
6		-		0	----------------
7		-		0	----------------
8	09:35	-	09:44	9	OTHER
8	09:53	-	10:05	12	OTHER
12	07:52	-	08:10	18	HARDWARE
12	09:37	-	09:44	7	HARDWARE
12	14:52	-	14:59	7	HARDWARE
12	15:09	-	15:15	6	HARDWARE
12	15:24	-	15:45	21	OTHER
13	09:31	-	10:03	32	HARDWARE
13	10:12	-	10:52	40	HARDWARE
14	02:35	-	03:00	25	OTHER
15	07:50	-	08:34	44	OTHER
15	09:48	-	10:10	22	OTHER
15	12:19	-	12:29	10	OTHER
15	12:39	-	12:54	15	OTHER
15	15:41	-	15:55	14	SOFTWARE
18		-		0	----------------
19	13:40	-	14:54	14	SOFTWARE
20	08:08	-	08:16	8	HARDWARE
20	08:25	-	09:25	60	HARDWARE
20	11:12	-	11:33	21	OTHER
20	13:05	-	13:08	3	OTHER
21		-		0	----------------
22	21:30	-	07:44	614	HARDWARE

TOTAL HARDWARE DOWN TIME = 868 TOTAL SOFTWARE DOWN TIME = 28 TOTAL OTHER DOWN TIME = 469

TOTAL HARDWARE INTERRUPTIONS = 11 TOTAL SOFTWARE INTERRUPTIONS = 2 TOTAL OTHER INTERRUPTIONS = 12

CDC-6600 DOWN TIME CHRONOLOGY FOR 26 OCT - 25 NOV 1976

DAY OF MONTH	TIME SYSTEM STOPPED		TIME SYSTEM UP	MINUTES SYSTEM DOWN	CAUSE OF INTERRUPTION
26	16:34	-	16:50	16	OTHER
27		-		0	--------------
28	11:00	-	11:09	9	OTHER
28	01:50	-	02:15	25	OTHER
29	13:17	-	14:24	67	HARDWARE
29	16:36	-	16:45	9	OTHER
30		-		0	--------------
1	11:57	-	12:06	9	HARDWARE
1	12:35	-	12:50	15	OTHER
1	13:40	-	13:50	10	SOFTWARE
1	14:04	-	14:12	8	SOFTWARE
1	15:05	-	15:38	33	HARDWARE
2		-		0	--------------
3	10:56	-	14:09	193	HARDWARE
4	13:34	-	13:41	7	HARDWARE
5	06:00	-	07:44	104	HARDWARE
8	07:45	-	10:45	180	HARDWARE
9		-		0	--------------
10		-		0	--------------
11	09:17	-	09:30	13	OTHER
12	07:47	-	07:50	3	HARDWARE
12	08:22	-	09:19	57	HARDWARE
12	09:25	-	10:26	61	HARDWARE
12	11:30	-	11:53	23	OTHER
12	18:00	-	18:12	12	HARDWARE

CDC-6600 DOWN TIME CHRONOLOGY FOR 26 OCT - 25 NOV 1976

DAY OF MONTH	TIME SYSTEM STOPPED		TIME SYSTEM UP	MINUTES SYSTEM DOWN	CAUSE OF INTERRUPTION
15		-		0	---------------
15	08:30	-	08:39	9	OTHER
16	08:48	-	09:32	44	HARDWARE
16	09:36	-	11:00	84	HARDWARE
16	16:30	-	16:40	10	HARDWARE
16	18:10	-	18:19	9	HARDWARE
16	18:50	-	19:04	14	HARDWARE
16	19:35	-	21:34	119	HARDWARE
16	22:26	-	22:31	5	HARDWARE
16	00:42	-	00:46	4	HARDWARE
17	09:12	-	12:50	216	HARDWARE
18		-		0	---------------
19	10:56	-	11:12	16	HARDWARE
19	11:21	-	11:30	9	OTHER
19	16:12	-	16:23	11	OTHER
19	16:33	-	16:47	14	OTHER
19	19:45	-	03:51	485	OTHER
20		-		0	---------------
22		-		0	---------------
23		-		0	---------------
24	09:52	-	09:59	7	HARDWARE
24	12:05	-	12:20	15	HARDWARE
24	17:26	-	17:37	11	HARDWARE

TOTAL HARDWARE DOWN TIME = 1280   TOTAL SOFTWARE DOWN TIME = 18   TOTAL OTHER DOWN TIME = 638

TOTAL HARDWARE INTERRUPTIONS = 24   TOTAL SOFTWARE INTERRUPTIONS = 2   TOTAL OTHER INTERRUPTIONS = 12

Appendix B. TRANSFORMED DATA

Date	Time			Interrupts		No. of Failures
	Up	Down	Repair	No.	Type	
26 May	-	5.30		0		0
27 May	-	0.08		2	S	2
	2.42	0.25			S	
28 May	11.90	1.35		1	O	1
1 Jun	12.55	0.63		2	S	2
	3.03	4.28			O	
2 Jun	9.88	0.15		1	S	1
3 Jun	-	-		0	-	0
4 Jun	-	-		0	-	0
7 Jun	-	-		0	-	0
8 Jun	64.85	0.17		1	O	1
9 Jun	22.83	0.17		1	H	1
10 Jun	12.78	5.30		1	O	1
11 Jun	2.12	6.72		2	O	1
	0.68*	0.10	7.50		O	
14 Jun	20.33	0.17		1	H	1
15 Jun	4.50	0.28		2	O	2
	8.63	0.18			O	
16 Jun	-	-		0	-	0
17 Jun	29.88	0.13		3	S	
	1.30	0.37	0.50		H	2
		0.13				
18 Jun	-	-		0	-	0
21 Jun	-	-		0	-	0
22 Jun	-	-		0	-	0
23 Jun	59.08	0.52		1	H	1
24 Jun	-	-		0	-	-
25 Jun	37.73	0.20		1	S	1
28 Jun	14.83	0.38		1	O	1
29 Jun	9.02	0.17		2	H	2
	2.53	0.35			O	
30 Jun	-	-		0	-	0
1 Jun	-	0.17			H	
	-	0.02		1	H	1
	-	0.23			H	
	29.97	0.67			H	
2 Jul	18.25	0.42			H	
	0	0.17		1	H	1
	-	0.17			O	
6 Jul	-	-		0	-	0
7 Jul	-	0.19			H	
	-	0.25			O	

*These up-times will be deleted to form the operating times.

Date	Time			Interrupts		No. of Failures
	Up	Down	Repair	No.	Type	
	36.03	0.28		3	H	1
	0.27*	0.05	1.83		H	
	1.05*	0.18			H	
8 Jul	10.05	1.28			O	
	6.05	0.17		3	S	3
	4.25	0.37			H	
9 Jul	-	-		0	-	0
12 Jul	18.35	0.72			H	
	4.07	0.13	1.44	3	H	2
	0.28*	1.03			H	
13 Jul	-	-		0	-	0
14 Jul	26.62	0.40		1	H	1
15 Jul	17.95	0.17			H	
	2.13	0.12	1.32	3	H	2
	0.58*	0.62			H	
16 Jul	-	-		0	-	0
19 Jul	-	-		0	-	0
20 Jul	-	-		0	-	0
21 Jul	67.22	1.25		1	H	1
22 Jul	15.75	0.10		1	O	1
23 Jul	-	-		0	-	0
26 Jul	30.23	0.20		1	O	1
27 Jul	-	-		0	-	0
28 Jul	-	-		0	-	0
29 Jul	-	-		0	-	0
30 Jul	65.22	0.17		1	O	1
2 Aug	12.27	2.67		2	H	2
	3.63	0.12			H	
3 Aug	-	0.17		0	S	0
4 Aug	25.32	0.48			H	
	1.23*	1.33	3.04	3	H	2
	1.88	0.27			S	
5 Aug	-	-		0	-	0
6 Aug	35.38	0.25		1	H	1
9 Aug	6.50	0.15		2	H	2
	7.92	0.37			O	
10 Aug	-	-		0	-	0
11 Aug	-	-		0	-	0
12 Aug	-	-		0	-	0
13 Aug	-	-		0	-	0
16 Aug	85.57	12.35**		1	H	1
17 Aug	1.95	0.27		1	S	1

*These up-times will be deleted to form the operating times.

**12.35 hours from 2100 hours 16 Aug to 0935 hours 17 Aug.

Date	Time			Interrupts		No. of Failures
	Up	Down	Repair	No.	Type	
18 Aug	20.20	0.28		1	O	1
19 Aug	7.95	1.68			H	
	5.60	0.17		3	O	3
	1.05	3.58			H	
20 Aug	-	-		0	-	0
23 Aug	21.93	0.32		1	O	1
24 Aug	22.75	4.45		1	O	1
25 Aug	5.92	0.30		2	O	2
25 Aug	3.13	0.70			H	
26 Aug	-	--		0	-	0
27 Aug	-	-		0	-	0
30 Aug	-	-		0	-	0
31 Aug	59.38	0.12	1.30	0	O	
	0.33*	0.32		4	H	2
	0.k8*	1.00	2.77		O	
	0.63*	1.82			H	
1 Sep	-	-		0	-	0
2 Sep	33.38	0.13		1	O	1
3 Sep	-	-		0	-	0
7 Sep	26.12	12.42		1	O	1
8 Sep	6.30	0.28		2	O	2
	6.20	0.42			S	
9 Sep	-	-		0	-	0
10 Sep	-	-		0	-	0
13 Sep	-	-		0	-	0
14 Sep	56.98	0.37		1	H	1
15 Sep	-	-		0	-	0
16 Sep	33.12	0.25			H	
	6.28	0.17		3	S	3
	1.05	0.67			O	
17 Sep	16.25	0.28	2.66	2	O	
	1.38	1.00			O	
20 Sep	2.83	0.75			H	
	0.65	0.05		4	O	2
	0.72*	0.28	1.82		O	
	0.22*	0.55			O	
21 Sep	-	-		0	-	0
22 Sep	-	-		0	-	0
23 Sep	-	-		0	-	0
24 Sep	--	-		0	-	0
27 Sep	78.78	0.83	2.09	2	H	1
	0.83*	0.43			H	

*These up-times will be deleted to form the operating times.

Date	Time			Interrupts		No. of Failures
	Up	Down	Repair	No.	Type	
28 Sep	20.98	0.23	2.09	1	O	1 1
29 Sep	-	-	2.80	0	-	0
30 Sep	24.68	4.55**		1	O	1
1 Oct	-	-		0	-	0
4 Oct	-	-		0	-	0
5 Oct	-	-		0	-	0
6 Oct	-	-		0	-	0
7 Oct	-	-		0	-	0
8 Oct	96.53	0.15		2	O	1
	0.15*	0.20	0.50		O	
12 Oct	14.03	0.30	1.87		H	
	1.45*	0.12			H	
	5.13	0.12	0.39	5	H	3
	0.17*	0.10			H	
	0.15	0.35			O	
13 Oct	10.02	0.53	1.35	2	H	1
	0.15*	0.67			H	
14 Oct	-	0.42		0	O	0
15 Oct	29.47	0.73	2.33		O	
	1.23*	0.37			O	
	2.15	0.17	0.59	5	O	3
	0.17*	0.25			O	
	2.78	0.23			S	
18 Oct	-	-		0	-	0
19 Oct	30.25	0.23		1	S	1
20 Oct	10.48	0.13	1.28		H	
	0.15*	1.00		4	H	2
	1.78	0.35	1.93		O	
	1.53*	0.05			O	
21 Oct	-	-		0	-	0
22 Oct	40.87	10.23**	2.50	1	H	1
26 Oct	25.07	0.27		1	O	1
27 Oct	-	-		0	-	0
28 Oct	26.67	0.15		1	O	1
	-	0.42			O	
29 Oct	18.38	1.12		2	H	2
	2.20	0.15			O	
30 Oct	-	-		0	-	0

*These up-times will be deleted to form the operating times.

**1023 hours from 2130 hours 22 Oct to 0744 hours 23 Oct.

Date	Time			Interrupts		No. of Failures
	Up	Down	Repair	No.	Type	
1 Nov	27.70	0.15			H	
	0.48	0.25			O	
	0.83	0.17	0.53	5	S	4
	0.23*	0.13			S	
	0.88	0.55			H	
2 Nov	-	-		0	-	0
3 Nov	27.80	3.22		1	H	1
4 Nov	15.67	0.12		1	H	1
5 Nov	-	1.73		0	H	0
8 Nov	26.57	3.00		1	H	1
9 Nov	-	-		0	-	0
10 Nov	-	-		0	-	0
11 Nov	47.28	0.22		1	O	1
12 Nov	14.53	0.05			H	
	0.53*	0.95	2.65		H	
	0.10*	1.02		5	H	3
	1.07	0.38			O	
	6.12	0.20			H	
15 Nov	-	-		0	-	0
16 Nov	22.80	0.15			H	
	0.15*	0.73	2.50		H	
	0.07*	1.40			H	
	5.50	0.17		8	H	2
	1.50*	0.15			H	
	0.52*	0.23	6.02		H	
	0.53*	1.98			H	
	0.87*	0.08			H	
	-	0.07			H	
17 Nov	2.83	3.60		1	H	1
18 Nov	-	-		0	-	0
19 Nov	30.60	0.27			H	
	0.15	0.15			O	
	4.70	0.18		5	O	4
	0.17*	0.23	0.58		O	
	2.97	8.08**	4.25		O	
20 Nov	-	-		0	-	0
22 Nov	-	-		0	-	0
23 Nov	-	-		0	-	0
24 Nov	50.87	0.12			H	
	2.10	0.25		3	H	3
	5.10	0.18			H	

*8.08 hours from 1945 hours 19 Nov to 351 hours 20 Nov.

**These up-times will be deleted to form the operating times.

DISTRIBUTION

	No. of Copies
Defense Documentation Center Cameron Station Alexandria, Virginia 22314	12
Commander US Army Materiel Development and Readiness Command	
Attn: DRCRD	1
DRCDL	1
5001 Eisenhower AVenue Alexandria, Virginia 22333	
Superior Technical Services	
Attn: Mrs. T. Ward 4308 Governors Drive Huntsville, Alabama 35805	1
DRCPM-MD-T, Mr. Hase	1
-T-P, Mr. Brower	1
Mr. Adams	1
Mr. Short	1
DRSMI-FR, Mr. Strickland	1
-LP, Mr. Voigt	1
-W, Mr. Calcote	1
-WS, Mr. Collins	1
-WT, Mr. Whigham	1
DRDMI-X, Dr. McDaniel	1
-T, Dr. Kobler	1
-TG, Mr. Huff	1
-TGN, Mr. Kelly	1
Mr. Campbell	10
-TD, Dr. Grider	1
-TB	3
-TI (Record Set)	1
(Reference Set)	1